14304

DRAFT

Crystalline-matrix Breccia

2498.9 grams

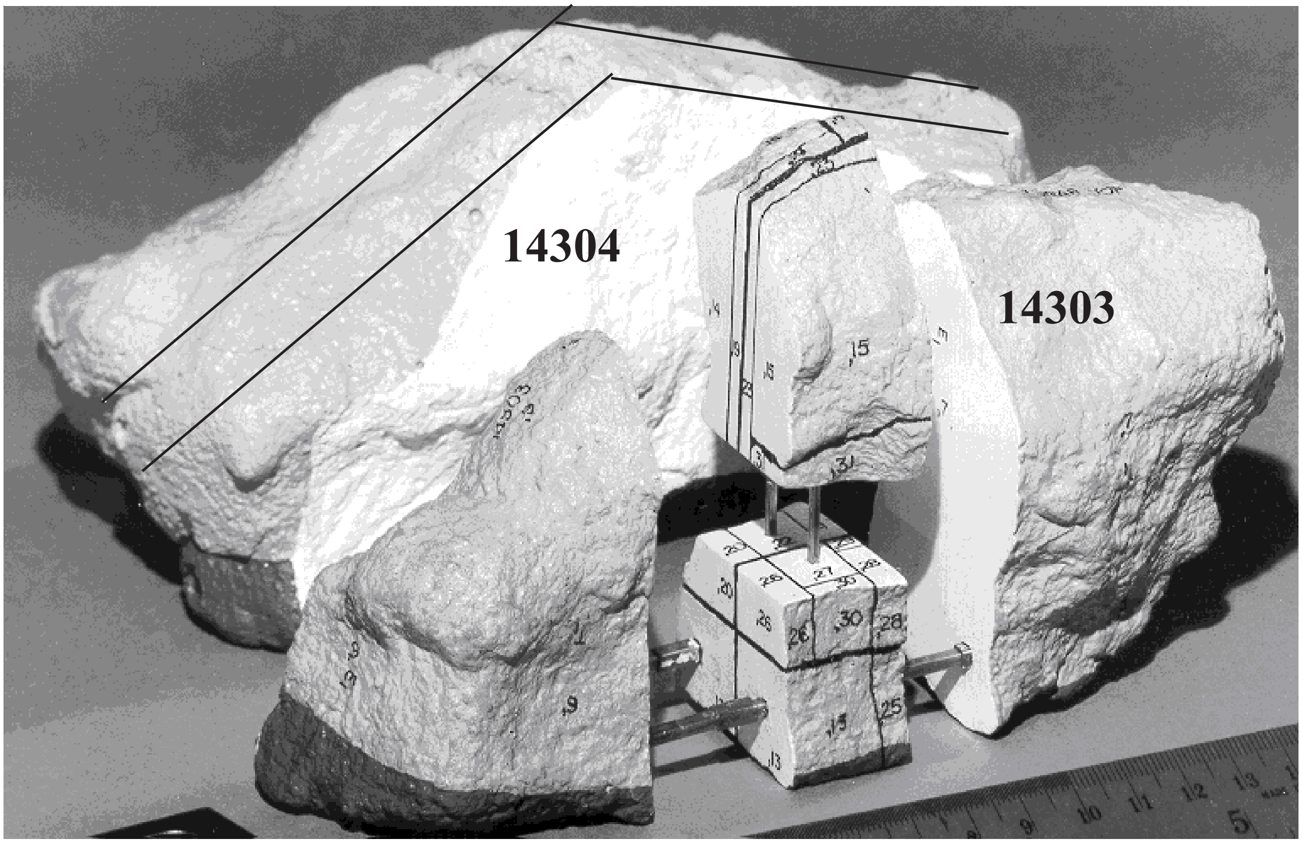


Figure 1: Photo of exploded parts diagram for 14303-14304 pair. The soil line is painted dark on the bottom. Slab is about 1 inch thick. NASA S78-26757 Approximate trace of slab thru 14304 indicated by lines.

Introduction

14304 was collected as a "football-sized" rock specifically to allow study of solar-galactic cosmic ray interaction with the lunar surface, but it was apparently never used for that purpose because of poor documentation. 14304 was returned in same bag as 14303, 14302-14305 and numerous smaller fragments. It has been found to be a part of 14303 (figure 1). Probably some of the small fragments in the same bag were also part of the 14303-14304 pair (see section on 14303). Samples 14304-14303 and 14305-14302 were picked up during the first EVA and documented by photos AS14-67-9390 and AS14-67-9392. They were from an area between the LM and the ALSEP site (Swann et al. 1977).

About 1986, Klaus Keil initiated a consortium study of 14304 (originally considered a Posterity Sample). His group was the first to extract clasts to study their chemical and mineralogical composition (Goodrich et al. 1986).

Petrography

McGee et al. (1979) describe 14304 as a clast-rich impact-melt breccia characterized by a wide range of mineral and lithic clast types in a recrystallized matrix. The matrix consists of irregularly shaped patches of lighter and darker areas, caused by fewer and larger ilmenite crystals in the coarser-grained lighter areas as compared with more abundant and smaller ilmenite grains in the fire-grained darker matrix patches. The matrix contains both small voids between grains and

Figure 2: Top surface of 14304 showing micrometeorite craters. NASA S77-23099. Cube is 1 inch.

Figure 3: Freshly broken side of 14304, facing 14303. NASA S77-21972. Cube is 1 cm.

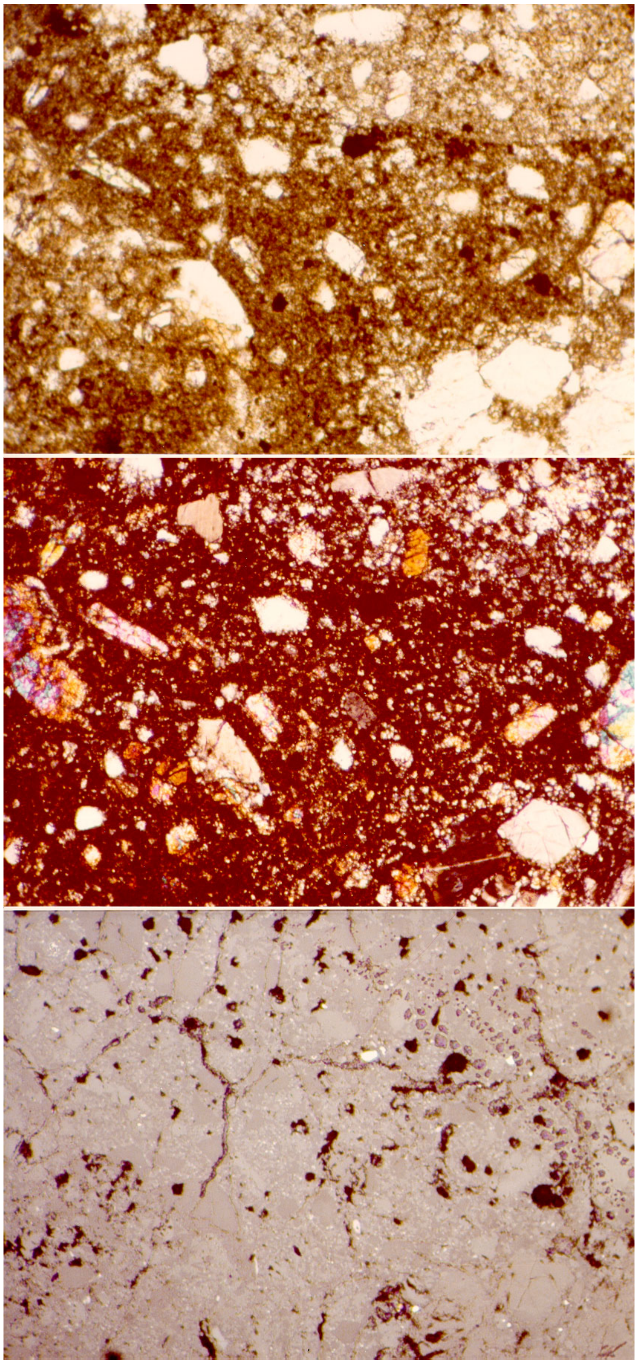


Figure 4: Photomicrographs of thin section 14304,13 showing clastic nature of matrix. Top is with plane-polarized light S79-27383; middle is cross-polarized S79-27384; bottom is reflected light S79-27382. All are 1.3 mm across of same view.

larger vugs up to 0.75 mm across. No glass clasts are present (Chao et al. 1971).

The mineral clast population is dominated by subangular to subrounded clasts of plagioclase (up to 0.7 mm) with common undulatory extinction. Pyroxene and olivine clasts (up to 0.3 mm) are highly

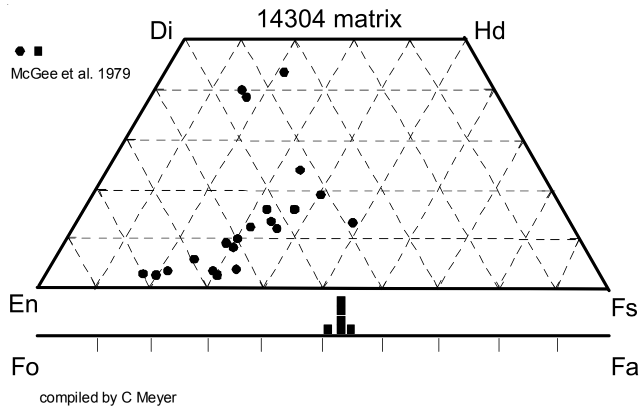


Figure 5: Pyroxene and olivine composition of matrix of 14304 (from McGee et al. 1977).

fractured and sometimes contain opaque phases. Fragments of irregularly shaped ilmenite, amoeboid-shaped troilite and micron-sized blebs of Fe-Ni are scattered randomly throughout the matrix.

Goodrich et al. (1986), Warren et al. (1987), Neal et al. (1989) and Snyder et al. (1995) have studied numerous lithic clasts extracted from the matrix of 14304.

Significant Clasts

Troctolite clast "a" ~ 1 cm.

Goodrich et al. (1986) described clast "a" (,96 and ,126) as ~ 40-50% coarse-grained olivine and plagioclase (1 mm) with a cumulate texture (minerals only slightly shocked). The olivine (Fo_{87}) has low CaO typical of plutonic fragments. Plagioclase is $An_{93.5}$ (figure 6). The REE content is high with a "bow-shaped" pattern (figure 8). It was found to be pristine (Warren 1993).

Spinel Troctolite clast "q" TS,109 TS,251

Thin section ,109 has a clast of spinel troctolite with plagioclase (An_{94}), olivine (Fo_{91}) and spinel (11% Cr_2O_3). Warren (1993) lists it as pristine. Shervais and McGee (1998) give ion probe analyses of minerals in this clast.

Alkali Anorthosite clast "b" ,122 ,100 ,212 ,214 ,267

This white clast is estimated 7 – 9 mm in diameter (Goodrich et al. 1986), Warren et al. 1987, Snyder et al. 1995). It has been dated by Rb-Sr and Sm – Nd (figure 14). It is mostly (~95%) plagioclase (An_{81}, but Snyder et al. reported a wider range).

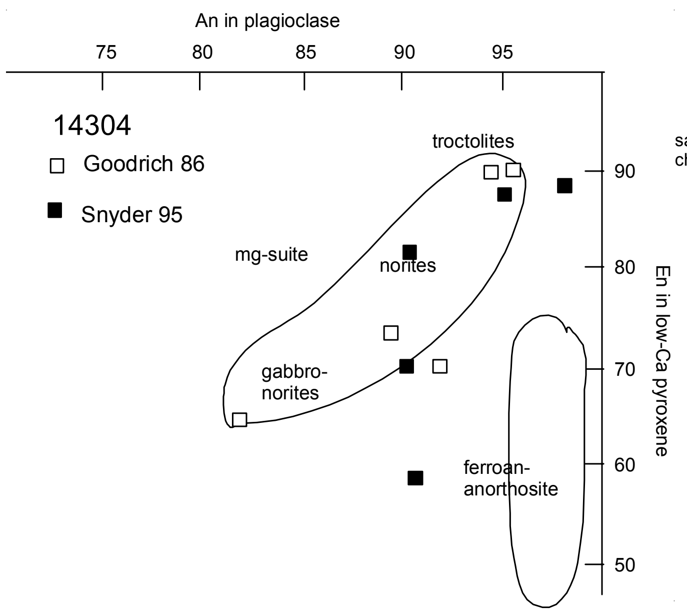


Figure 6: Mineral compositions of anorthosite, troctolite and norite clasts in 14304 (from Goodrich et al. 1986 and Snyder et al. 1995).

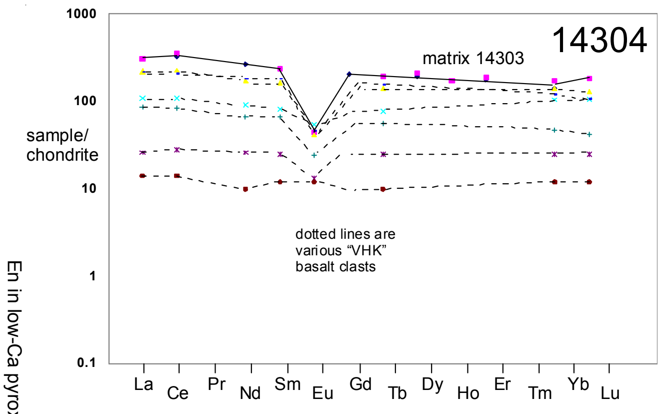


Figure 7: Normalized rare-earth-element diagram for 14304 VHK clasts a la Neal et al. 1989. Data for matrix is from 14303 and 14305 sawdust.

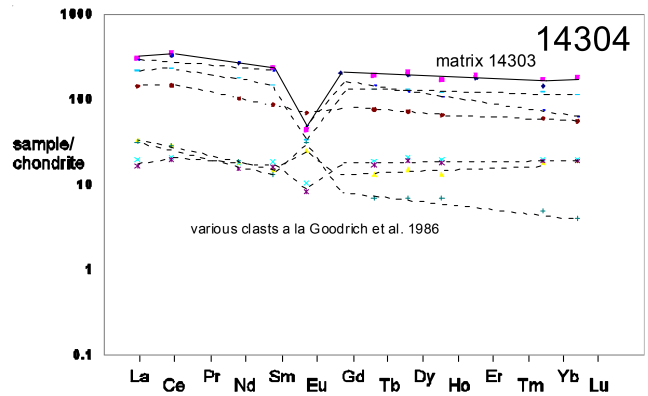


Figure 8: Normalized rare-earth-element diagram for variopus clasts a la Goodrich et al. 1986. Data for matrix is from 14303 and 14305 sawdust.

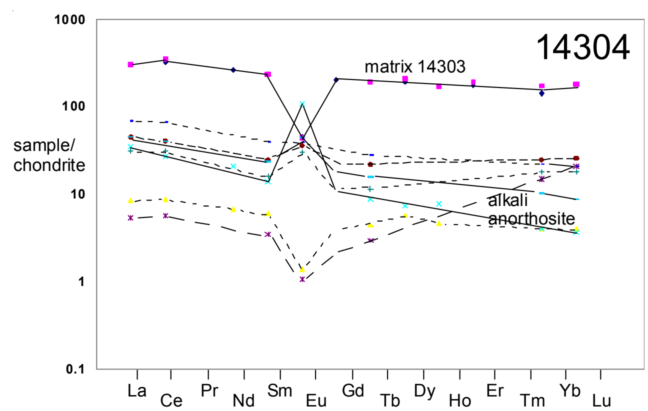


Figure 9: Normalized rare-earth-element diagram for 14304 clasts a la Warren et al. 1987 and Snyder et al. 1995. Data for matrix is from 14303 and 14305 sawdust. Peculuar alkali anorthosite merrits solid line - note the high Eu content.

Dunite clast "d" ,121 ,92

Goodrich et al. (1986) and Warren et al. (1987) studied an almost pure olivine clast (2 – 6 mm). It had a texture with smaller olivine crystals (Fo_{89}) imbedded in large ones, with occasional "mosaic" texture.

Alkali Norite clast "g" TS,30 ,86 ,87 ,270 ,272, TS,209, TS,210

This clast (4 x 7 mm) was first seen in thin section (,30, 75% pyroxene En_{63-66}, 14% plagioclase An_{82}, 2% phosphate). Veins in this clast have K-feldspar, ternary feldspar, whitlockite and apatite (Goodrich et al. 1986). Warren (1993) found that it was "pristine", and Snyder et al. (1995) provided isotopic data.

VHK Basalt Clasts

Neal et al. (1989a and b) studied 6 clasts of VHK basalt (which are called that because they have very high potassium content) extracted from 14304. However, their wide range in trace element content makes it look like the portions analyzed may have had some remaining matrix attached (figure 7). They are not listed as pristine in the compilation by Warren (1993).

Basalt clasts "c" TS,91, ,113 ,127 and "i" TS,58 ,108 ,128

Goodrich et al. (1986) analyzed two basalt clasts from 14304 and gave mineral analyses. Shih et al. (1987) were able to date two of them (figures 10 -13). They

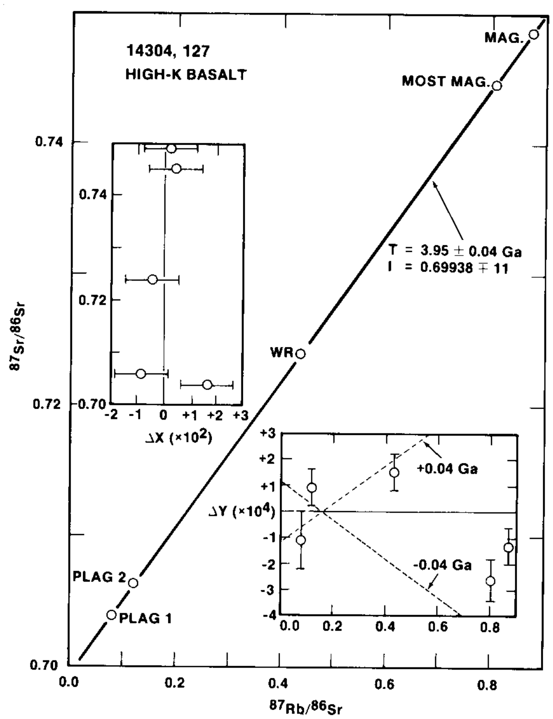


Figure 10: Rb/Sr isochron for VHK basalt fragment 14304,127 (from Shih et al. 1987).

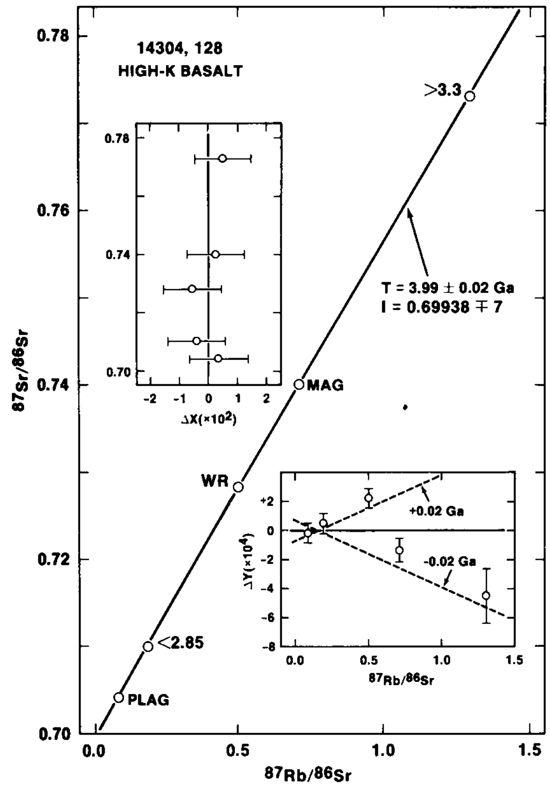


Figure 11: Rb/Sr isochron for VHK basalt clast 14304,128 (from Shih et al. 1987).

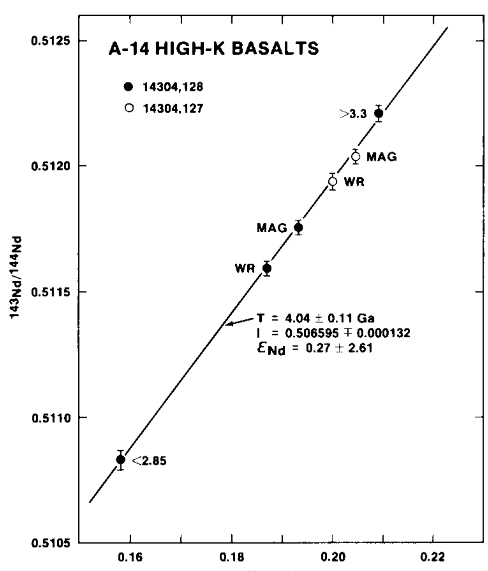


Figure 12: Sm/Nd whole rock isochron for VHK basalts from 14304 (Shih et al. 1987).

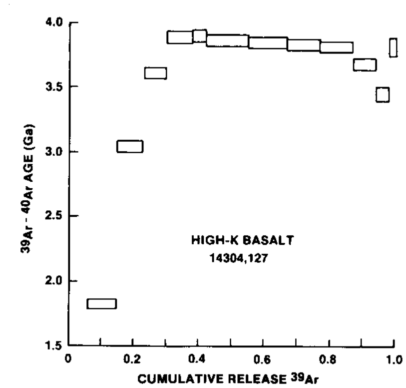


Figure 13: Ar/Ar plateau diagram for VHK basalt clast in 14304 (from Shih et al. 1987).

Summary of Age Data for 14304

	Rb/Sr	Sm/Nd	Ar/Ar	
Snyder et al. 1995	4.336 ± 0.081b.y.	4.108 ± 0.053		alkali anorthosite
		4.108 ± 0.044		norites
Shih et al. 1987	3.95 ± 0.04 b.y	4.04 ± 0.11	?	VHK basalts
	3.99 ± 0.02			

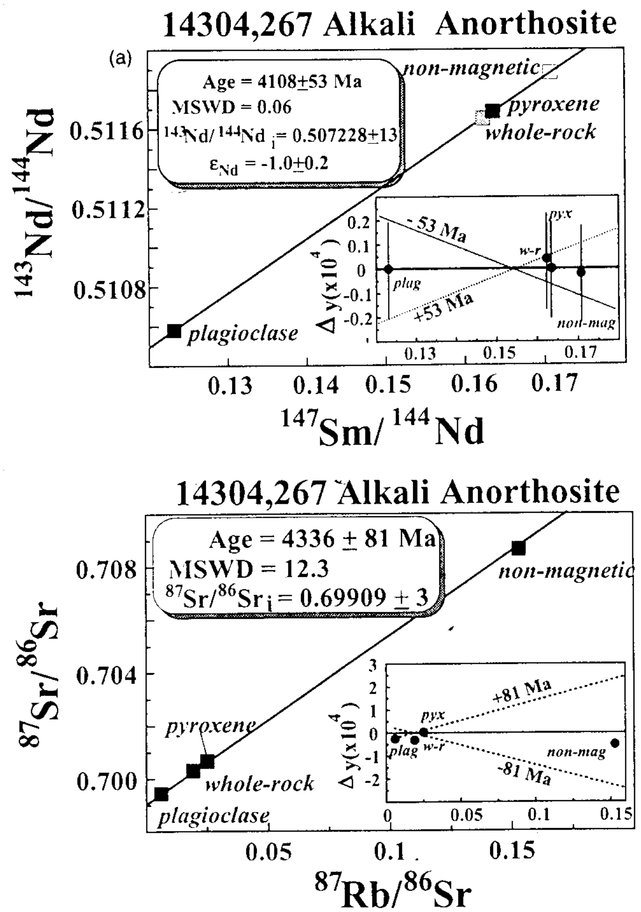


Figure 14: Sm-Nd and Rb-Sr isochrons for alkali anorthosite clast ,267 in 14304 (from Snyder et al (1995b).

had Rb contents intermediate between mare basalts and VHK basalts. Their "pristinity" has not been proven.

Chemistry

The bulk chemical composition of 14304 was found to be similar to that of other Apollo 14 breccias (Christian et al. 1976). The trace element composition of the matrix of 14304 has not been determined, but the analysis of 14303 by Brunfelt et al. (1972) will have to suffice. The sawdust from 14305 is similar and is likely to be even more representative, because the analyses of very small portions of the matrix of these breccias may not be as representative as the sawdust (Philpotts et al. 1972).

The composition of small clasts dug out of the matrix is problematical, because it is inherently difficult to avoid contamination by the trace-element-rich matrix. However, the analyses exist (tables, figures 7 - 9) and the wide range in trace element content has even been attributed to assimilation of country rock by the magma

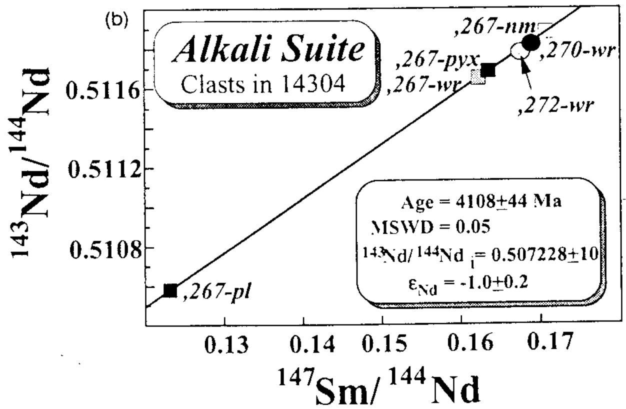


Figure 15: Sm-Nd whole rock isochron for norites in 14304 (Snyder et al 1995b).

during assent to the surface (Snyder et al. 1995). However, Goodrich et al. (1986) showed that clasts in 14304 have reacted with the breccia matrix!

Radiogenic age dating

Shih et al. (1987) dated two clasts of VHK basalt from 14304 (figures 10 - 13). Snyder et al. (1995) dated alkali anorthosite clast 14304,267 by Sm-Nd at 4.108 Ga (figure 14). Snyder et al. (1995) have provided further isotopic data on some of the clasts.

Processing

Originally collected as one of the "football-sized rocks" for solar and cosmic ray studies, 14304 broke up in the sample bag (#1027). In 1977, the models for 14303 and 14304 were found to fit together – see figure 1.

Originally a "posterity" sample, 14304 wasn't studied until 1986 when a thick slab was cut lengthwise through the main mass at the request of Klaus Keil. It has since been "pulled" apart by Larry Taylor in an effort to get at the clasts. There is no guidebook.

Table 1. Chemical composition of 14304 (clasts).

	,168	,176	,180	,148	,152	,164									
reference	Neal89							Goodrich86							
weight	VHK basalts							,95	,113	,108	,48	,79	,69	,77	
SiO2 %	49	52.1	46.6	47.4	48.3	46.3									
TiO2	1.86	1.07	2.22	1.5	2.27	5.94		0.17			0.43		<0.67	1.28	(a)
Al2O3	16	15.1	12	14.2	15.1	11.9		16.6			31.4	28	36.3	20.2	(a)
FeO	10.6	10.2	15.8	15.8	12.6	15.8	(a)	5.53	17.2	17.9	2.87	0.22	2.2	8.1	(a)
MnO	0.15	0.15	0.28	0.21	0.16	0.17		0.075	0.075	0.248	0.263	0.037	0.006	0.103	(a)
MgO	9.56	10.4	9.8	10	7.9	7.2		24			3.35	1.82	5.93	6.6	(a)
CaO	10.8	9.06	11	9.7	11.7	10		8.7	9.1	9.7	17.1	13.6	20.4	12.6	(a)
Na2O	0.6	0.6	0.51	0.4	0.56	0.71	(a)	0.28	0.3	0.24	0.91	0.36	0.5	0.67	(a)
K2O	0.96	1.07	1.22	0.35	1.11	1.71		0.15	0.32	0.33	0.22	0.08	0.1	0.9	(a)
P2O5	0.35	0.07													
S %															
sum															
Sc ppm	29.9	22.2	58.7	52.1	53.8	61.5	(a)	6.4	48.9	65	5.5	0.39	0.76	15	(a)
V								29			18	<17	<25	26	(a)
Cr	1262	1153	3450	3530	2560	2040	(a)	1210	4800	4980	370	590	150	1180	(a)
Co	20.2	15.8	32.6	34	36.5	34.9	(a)	27	41	45	9.2	0.71	730	17.8	(a)
Ni	170	79		<120	130	93	(a)	70	17	26	101	20	5900	676	(a)
Cu															
Zn															
Ga								2.9	2.3	2.2	7.4	3.3	5.4	5.1	(a)
Ge ppb															
As															
Se															
Rb	28	43	38				(a)	1.9	5.8	5.8	1.5	<3	<20	31	(a)
Sr	156	217	130				(a)	106	53	80	282	175	280	169	(a)
Y															
Zr	730	780	70				(a)	53	54	125	490	28	44	850	(a)
Nb															
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm	1.31	1.86	0.27	0.36	1.7	2.2	(a)	0.067	0.21	0.24	0.088	<0.12	<0.17	1.33	(a)
Ba	920	1160	202	60	560	820	(a)	270	103	111	840	260	320	930	(a)
La	51.4	25.2	6.11	3.33	20.5	50.6	(a)	7.7	4.6	3.9	34	7.7	69	51	(a)
Ce	135	66	16.8	8.5	50	126	(a)	17.7	12.6	11.8	88	17.4	200	139	(a)
Pr															
Nd	78	41	12	4.5	30	83	(a)	8.3	8.1	7	47	8.5	125	80	(a)
Sm	23.7	12.1	3.74	1.78	9.66	26.6	(a)	2.24	2.74	2.4	12.8	1.88	32	21.9	(a)
Eu	2.3	3.02	0.74	0.68	1.35	2.56	(a)	1.42	0.59	0.47	3.9	1.82	2.78	1.91	(a)
Gd															
Tb	5.13	2.82	0.89	0.37	2	5.6	(a)	0.48	0.69	0.61	2.78	0.24	5.3	4.8	(a)
Dy								3.6	5.1	4.7	17.8	1.6	30.2	32.4	(a)
Ho								0.74	1.1	0.99	3.7	0.39	6	6.7	(a)
Er															
Tm															
Yb	22.6	16.8	4.08	2.03	7.7	19.6	(a)	3	3.2	3.1	9.8	0.85	12.2	20	(a)
Lu	3.14	2.56	0.61	0.3	1.03	2.57	(a)	0.47	0.49	0.47	1.36	0.098	1.52	2.8	(a)
Hf	18.7	21.3	3	1.6	7.1	18.9	(a)	1.27	2.1	2	11.4	0.4	0.43	20.6	(a)
Ta	2.44	2.53	0.59	0.31	1.11	3.3	(a)	0.131	0.39	0.41	0.97	0.062		2.62	(a)
W ppb															
Re ppb															
Os ppb															
Ir ppb								<1.1		<4	2	<2.5			(a)
Pt ppb															
Au ppb									<0.8	<1		3.4	15	<2.3	(a)
Th ppm	10.9	11.4	0.92	0.62	3.2	5.2	(a)	0.79	0.6	0.49	6	0.32	7	12.7	(a)
U ppm	3.26	4.79	0.14	0.6	1.3	3.2	(a)	0.17	0.17	0.18	1.21	0.085	0.33	3.7	(a)

technique: (a) INAA

Table 2. Chemical composition of 14304 (clasts).

										14304		14303
reference	Warren87			Snyder95						Christian76		Rose
weight		alkali anor.		dunite	norite	norite	anor.	anor.		matrix		matrix
SiO2 %				40	48.1	47.4	56.9	51.8		45.91	(b)	47.49
TiO2	<0.83	<2.17	(a)	0.06	0.26	0.16	0.29	0.14		2.08	(b)	1.98
Al2O3	<1.3	35.9	(a)	0.72	23.9	24.8	31.9	34.4		13.44	(b)	16.05
FeO	9.8	0.5	(a)	12.1	4.45	3.97	1.67	0.75	(a)	16.56	(b)	10.96
MnO	0.11	0.008	(a)	0.12	0.1	0.06	0.03	0.01		0.24	(b)	0.15
MgO	51.4	<14.3	(a)	46.4	9.21	9.38	3.39	1.02		9.62	(b)	10.99
CaO	<1.3	18.2	(a)	0.52	13.4	13.6	17.9	18.9		10.36	(b)	10.03
Na2O	0.04	2.03	(a)	0.01	0.32	0.32	0.41	0.22	(a)	0.57	(b)	0.87
K2O	0.016	0.2	(a)		0.08	0.07	0.12	0.04		0.68	(b)	0.46
P2O5				0.07	0.03	0.04	0.05	0.02		0.31	(b)	0.56
S %												
sum												
Sc ppm	3	1.4	(a)	5.4	9.8	7.6	3.3	1.2	(a)			26
V	3.7	<64	(a)									46
Cr	1470	50	(a)	553	1549	1328	276	237	(a)	3705	(b)	1777
Co	63	1	(a)	60	18.9	18.5	7.7	2.3	(a)			28
Ni	315	<40	(a)	143	<29	116	66	21	(a)			245
Cu												20
Zn												
Ga	0.32	11.7	(a)									
Ge ppb												
As												
Se												
Rb	<13	<4.2	(a)									
Sr	<129	560	(a)									
Y												
Zr	<200	108	(a)	660	100	109	104	32	(a)			
Nb												
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm		<0.2	(a)									
Ba	<84	298	(a)	11	233	240	301	272	(a)			
La	2.02	8.2	(a)	1.26	10.5	7.31	16.5	10.5	(a)			
Ce	5.3	16.1	(a)	3.43	24.5	18.8	40.5	24.8	(a)			
Pr												
Nd	3.1	9.4	(a)									
Sm	0.88	1.98	(a)	0.52	3.64	2.31	5.93	3.49	(a)			
Eu	0.08	6.1	(a)	0.06	2	1.71	2.21	2.49	(a)			
Gd												
Tb	0.164	0.32	(a)	0.118	0.8	0.423	1.02	0.573	(a)			
Dy	1.4	1.8	(a)									
Ho	0.26	0.45	(a)									
Er												
Tm												
Yb	0.66	0.66	(a)	2.44	4.04	2.93	3.65	1.69	(a)			
Lu	0.096	0.09	(a)	0.512	0.63	0.431	0.519	0.215	(a)			
Hf	0.57	0.27	(a)	15.9	2.74	3.17	3.18	1.18	(a)			
Ta	<0.2	<0.13	(a)	0.049	0.318	0.226	0.456	0.156	(a)			
W ppb												
Re ppb												
Os ppb												
Ir ppb	<6	<2.5	(a)	<1.2			0.8	0.3	(a)			
Pt ppb												
Au ppb	<3.8		(a)	0.9	<1.2	1.8	1.1	<1	(a)			
Th ppm	0.28	0.159	(a)	0.36	1.19	0.67	1.8	1.06	(a)			
U ppm	0.074	<0.26	(a)	0.24	0.22	0.3	0.57	0.2	(a)			

technique: (a) INAA, (b) microchemical"

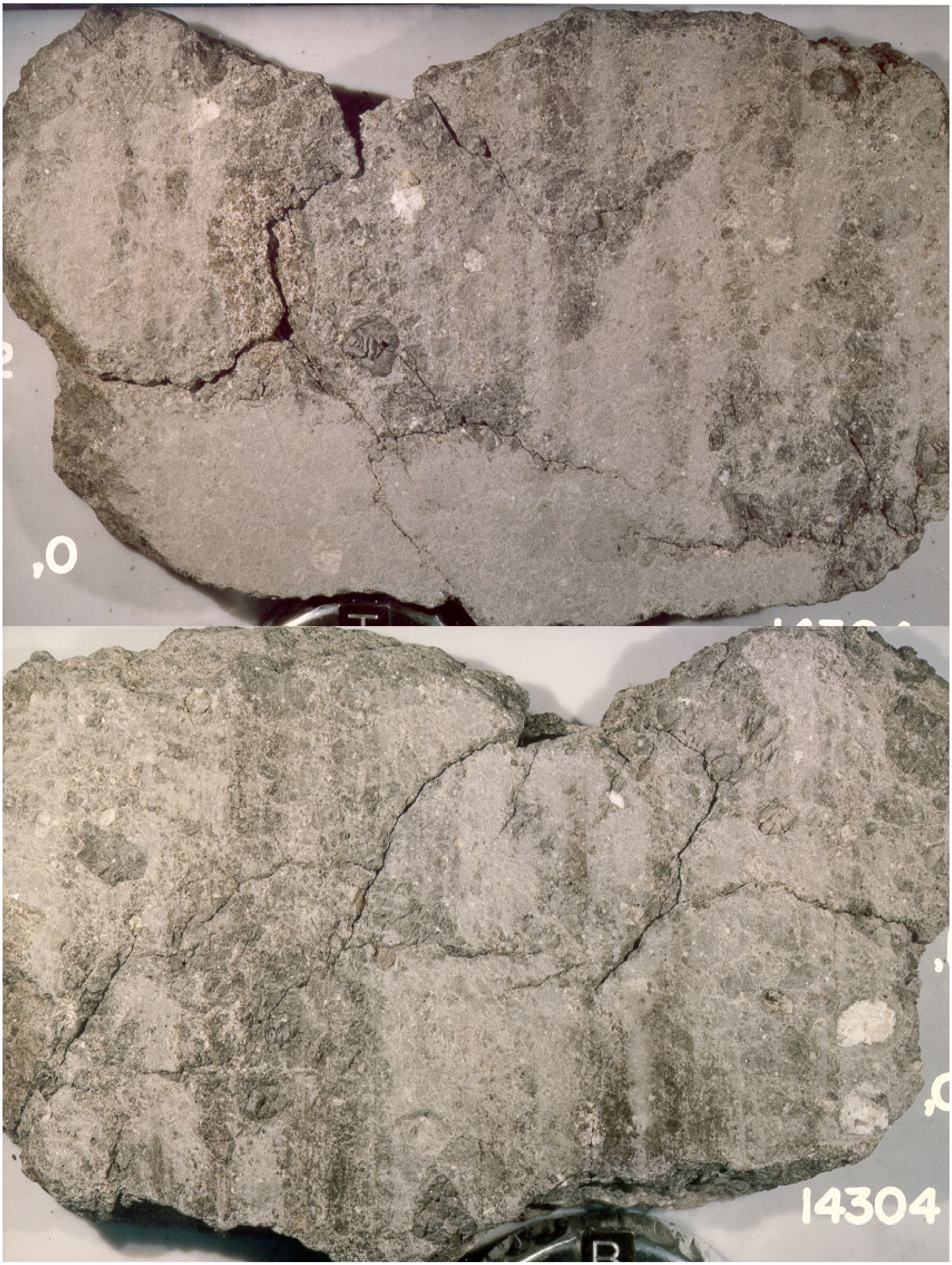
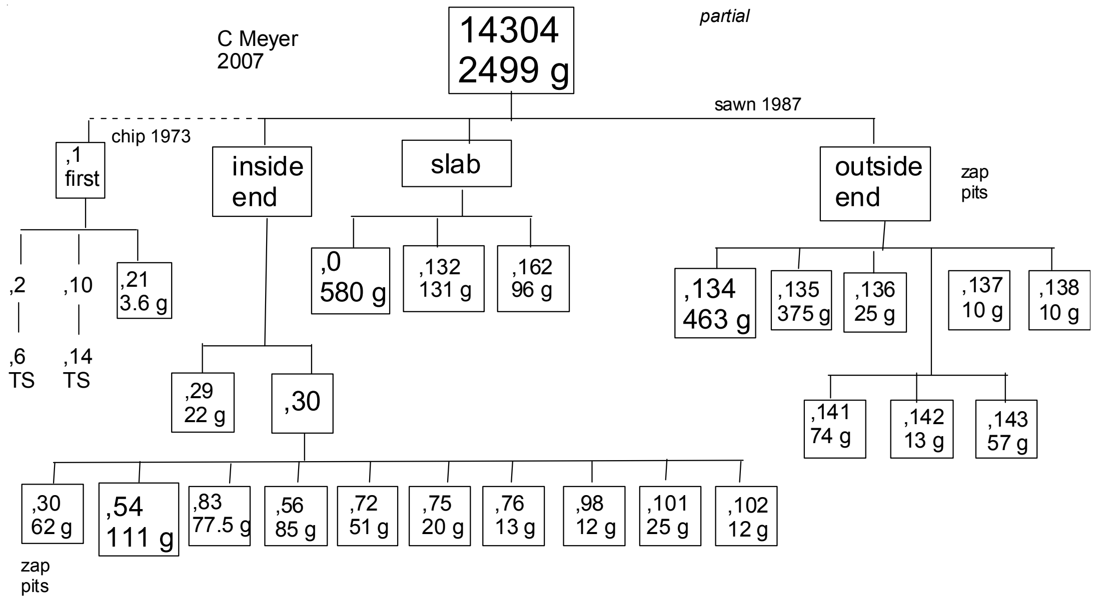


Figure : Front and back sides of slab sawn from 14304 in 1987. Top is NASA S87-45908; bottom is NASA S87-45910. Cube is 1 cm. ,0 designates "slab" for this rock only.



C Meyer
2007
14304
2499 g
partial
sawn 1987
chip 1973
,1
first
inside
end
slab
outside
end
zap
pits
,2
,10
,21
3.6 g
,6
TS
,14
TS
,0
580 g
,132
131 g
,162
96 g
,134
463 g
,135
375 g
,136
25 g
,137
10 g
,138
10 g
,29
22 g
,30
,141
74 g
,142
13 g
,143
57 g
,30
62 g
,54
111 g
,83
77.5 g
,56
85 g
,72
51 g
,75
20 g
,76
13 g
,98
12 g
,101
25 g
,102
12 g
zap
pits

References for 14304

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